REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01-03-2004	Conference Proceedings POSTPRINT	01-03-2003 -- 28-02-2004

4. TITLE AND SUBTITLE

Project Stork UAV/UGV Collaborative Initiative

5a. CONTRACT NUMBER F08637-03-C-6006

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER 63112F

6. AUTHOR(S)

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5d. PROJECT NUMBER 4918

5e. TASK NUMBER L4

5f. WORK UNIT NUMBER Q240FA5Z

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/MLQF

11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-ML-TY-TP-2004-4560

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement "A": Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

Published in Conference Proceedings of SPIE 5422 (2004) pp 414-425

14. ABSTRACT

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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	SAR	12	Walt Waltz
					19b. TELEPHONE NUMBER *(Include area code)*

Project Stork UAV/UGV Collaborative Initiative

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ABSTRACT

One of the key issues in military urban operations is the ability to obtain timely situational awareness of the target area. One solution utilizes Unmanned Ground Vehicles (UGVs) to provide this information but challenges remain as to how to accurately emplace and control these vehicles from extended ranges. This research and development project, Stork, demonstrated the capability to aerially insert a UGV from a UAV into an area of operations and then use a communications relay pod on the UAV to extend the range of control of UGVs. The UGV insertion was done using a parachute delivery system from after an altitude of 400 feet. The communications relay pod effectively increased the tele-operated control range of the UGV from typical 1-2 km line-of-sight limitation. Tele-operated control was demonstrated out to a distance of 26 km. Transparent to the physical elements of the demonstration was the integration of the Joint Architecture for Unmanned Systems (JAUS) on the UGVs which allows a single operator control unit (OCU) to control multiple disparate UGVs simply by selecting a particular UGV from a drop-down menu. The ability to control multiple vehicles on the ground at the extended range and switch control from one vehicle to the next and back was also successfully demonstrated.

Keywords: JAUS, Urban Operations, Common OCU, Unmanned Ground Vehicle (UGV), UAV

1. INTRODUCTION

1.1. Purpose

The purpose of this demonstration was to illustrate the military application to deliver an Unmanned Ground Vehicle (UGV) from an Unmanned Aerial Vehicle (UAV) and to use a UAV communication relay to extend the range of control beyond current system ranges for the UGV and its sensors in an urban environment. This capability will assist warfighters in urban operations, provide persistent target area information prior to and during high value missions, and increase the effectiveness of robotic control in support of Force Protection and Explosive Ordnance Disposal (EOD) assets. This demonstration was designed to:

- Demonstrate control of a UGV beyond current system ranges (1-2 km)
- Demonstrate the delivery of a UGV by a UAV into a desired area
- Demonstrate Joint Architecture for Unmanned Systems (JAUS) to control two UGVs
- Demonstrate UAV/UGV integration to provide persistent target information

1.2. Background

One of the key issues in urban operations is the ability to have timely situational awareness of the target area. One solution utilizes UGVs to provide this information to warfighters in an urban environment. The United States Special Operations Command (USSOCOM) has demonstrated many portions of control of robotics, but challenges remain as to how to accurately emplace and control these vehicles from extended ranges. Through their approved Advanced Concept Technology Demonstration (ACTD), called Pathfinder, the command attempts to seek ways to address the urban problem by combining technology to provide the most capable and lethal force possible. UAVB teamed with USSOCOM, Air Force Special Operations Command (AFSOC), and Air Force Research Laboratory (AFRL) at Tyndall, AFB and others to execute this initiative. This demonstration was designed in two phases:

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Unmanned Ground Vehicle Technology VI, edited by Grant R. Gerhart, Chuck M. Shoemaker, Douglas W. Gage,
Proceedings of SPIE Vol. 5422 (SPIE, Bellingham, WA, 2004) · 0277-786X/04/$15 · doi: 10.1117/12.553047

Phase I demonstrated a UGV delivery process, and Phase II demonstrated a UAV relay to extend the range of control for UGVs beyond current system ranges.

Transparent to the physical elements of this demonstration was the integration of Joint Architecture for Unmanned System (JAUS) for the control of the UGVs. JAUS defines interfaces (messages format) between software components, computing nodes (CPUs), and subsystems (robot vehicle, operator control unit, etc.). JAUS exists to ensure that the Department of Defense (DoD) UGVs are interoperable, can insert new capabilities easily, and remain open and scalable. A common architecture will save money in the long term, thus making UGVs more affordable.

1.3. Demonstration Assets

The architecture shown in Figure 1-1 illustrates the various assets used in Phase I and II of this demonstration. Two Sentry HP UAVs were used, one for each phase. The first UAV was configured to carry and drop, via parachute delivery, the Electric Expendable Landrover (EEL) UGV. The EEL drop occurred from 400 ft above ground level (AGL). The EEL was selected because its size, weight, and durability characteristics were compatible for air deployment. Two JAUS equipped UGVs, Matilda and All-purpose Remote Transport System (ARTS), were the UGVs controlled over the relay link by the Operator Control Unit (OCU). The second UAV was configured with the UGV communication relay mounted internally to act as a link from the UGV OCU to the UGVs. The "bent pipe" architecture utilized a L-band link from the OCU to the UAV and a Wireless Local-Area Network (WLAN) link from the UAV to the UGV.

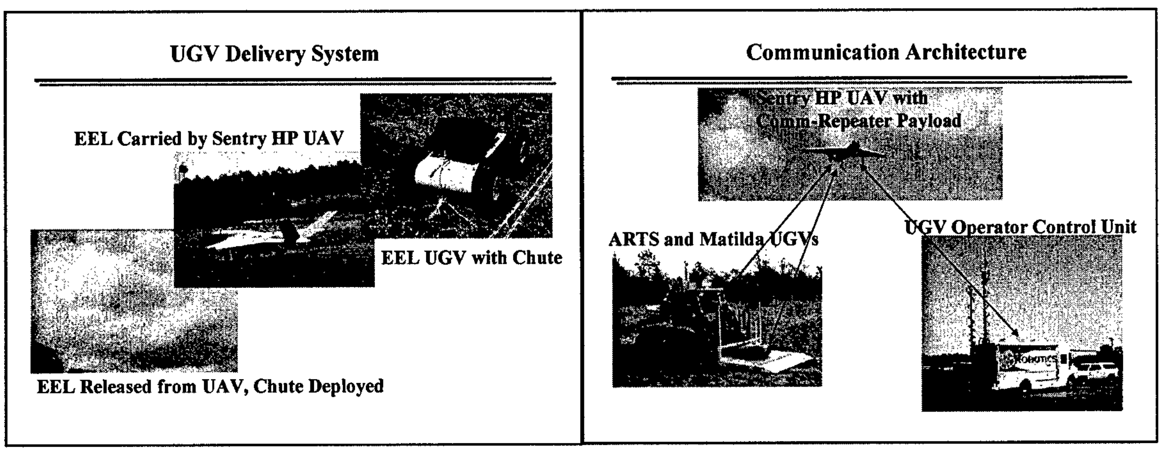

Figure 1-1: Architecture for Phase I and II

1.3.1. Sentry HP

The UAV airframe is a carbon fiber composite delta wing "V" tail design. The carbon fiber airframe is very resilient and damage tolerant, providing an extended service life for the entire system. The delta wing provides lower wing loading resulting in high payload to air vehicle weight ratio. The "V" tail design allowed for an internal payload volume capable of supporting the UGV communications relay and a UAV recovery parachute. The large wing cavities maximize fuel carrying capacity. The Sentry HP's demonstrated capability to airdrop up to 75 lbs on an airfield made it a viable candidate to drop the EEL (EEL weighed roughly 50 lbs). The UAV is quiet and small, which allows for discrete emplacement of the UGV. Modular construction allows for easy system upgrades or modifications, and withstands rough handling. The Sentry HP's design enables quick turnaround with ease of repair and simple checkout. A mature design contributes to high mean time between system aborts and system availability. The complete Sentry HP system includes a pneumatic launcher, which permits launches from confined, restricted, or unimproved launch sites, and a ground control station for mission planning, monitoring, and in-flight profile amendment. Recovery methods include wheels and an optional precision approach/landing parachute system, providing the capability of air vehicle recovery in small or unimproved landing areas.

Table 1-1: Sentry HP Data

SPECIFICATIONS		PERFORMANCE DATA	
Gross Weight:	325 lb.	Altitude:	16,000 ft.
Empty Weight:	180 lb.	Endurance:	8.0 hrs (with 10USG fuel)
Wingspan:	12.5 ft.	Max Speed:	100 kts.
Payload Weight:	75 lb internal.	Cruise Speed:	75 kts.
Length:	8.42 ft.	Loiter Speed:	65 kts.
Wing Area:	31.37 sq. ft.	Launch:	Pneumatic launcher or wheels
Power Plant:	2 cycle reduction driven; 36/24 Prop	Recovery:	Skid, wheels or parafoil
Fuel:	MOGAS/AVGAS		

1.3.2. Expendable Electric Landrover (EEL)

The EEL is a small, rugged, robotic sensor platform developed by Coastal System Station (CSS) Surf Zone Robotics team, under the sponsorship of Defense Threat Reduction Agency. The vehicle is an inexpensive, impact resistant, four-wheel drive vehicle that leverages the control system previously developed for amphibious crawlers. It can carry a wide variety of sensors and includes integrated color video. EEL can be tele-operated or fully autonomous. The vehicle shell is aluminum and commercial off-the-shelf (COTS) electronics are utilized for the control system. Internal orientation sensors allow the system to operate correctly even if flipped upside down. The EEL is 28 inches long by 18 inches wide, weighs only 50 pounds and can be carried internally by the Sentry HP UAV.

1.3.3. Matilda

Matilda is a rugged versatile, mobile, man-portable UGV for operation in both urban and field environments. The system provides users with reconnaissance, and under-vehicle inspections capabilities. In addition, the platform is capable of carrying and towing a variety of payloads and tools. The platform is tracked, 26 inches long, 20 inches wide, 12 inches tall, and weighs 40 pounds. The ground clearance is 4 inches. Speed is 3 feet/second, or 2 miles/hour. Two, 12-volt rechargeable batteries power the electric motors. The UGV has a forward pan and tilt camera assembly with a color, medium wide-angle driving camera. JAUS was added to this UGV for this demonstration. USSOCOM provided the Matilda for this initiative.

1.3.4. All-purpose Remote Transport System (ARTS)

The ARTS UGV is a commercially available, low ground pressure, rough-terrain, hydraulically powered, posi-tracked tractor converted to remotely operated platform. ARTS is currently used to provide standoff solutions for EOD operators to locate, remove, and neutralize Unexploded Ordnance (UXO) and Improvised Explosive Devices (IEDs). It also has a quick attachment mounting plate capable of employing and integrating various tools and attachments for a wide variety of missions. ARTS is a JAUS capable asset provided by AFRL's Robotics Research Group.

1.3.5. UGV Communications Repeater System

The UGV comm-repeater system is a wireless Radio Frequency (RF) relay system developed to show feasibility of extended unmanned ground vehicle operations to Beyond Line-of-Sight (BLOS) distances. In the traditional sense, unmanned vehicle operations are performed over LOS distances using point-to-point wireless communication equipment. Recent advances in both technology and unmanned vehicle system implementations have progressed to the point where multiple operator/vehicle operations are performed over network centric communications architectures. Using commercial WLAN equipment, the Robotics Research Group of AFRL, Tyndall AFB, FL, is currently demonstrating LOS operation of multiple unmanned ground vehicles from a single UGV OCU. The repeater described in the following paragraphs provides for extending network centric command and control of unmanned ground vehicles to BLOS by fielding a communication relay on a UAV.

A block diagram of the UGV comm-repeater including a host UAV system is depicted in Figure 1-2. The UAV system is comprised of a Ground Control Station (GCS) and a Sentry HP UAV. The unmanned ground vehicle system is comprised of an OCU, UGV Comm-Repeater System, and one or more UGVs. Communication between the GCS and UAV is implemented via an S-band RF telemetry link. Communication between the OCU and UGV(s) is implemented via the UGV comm-repeater system to include an L-band RF telemetry link and a WLAN link. In

this configuration, the UAV command/control link is completely isolated from the UGV comm-repeater links with the UAV used solely as an aerial platform to carry the airborne component of the UGV communications relay equipment.

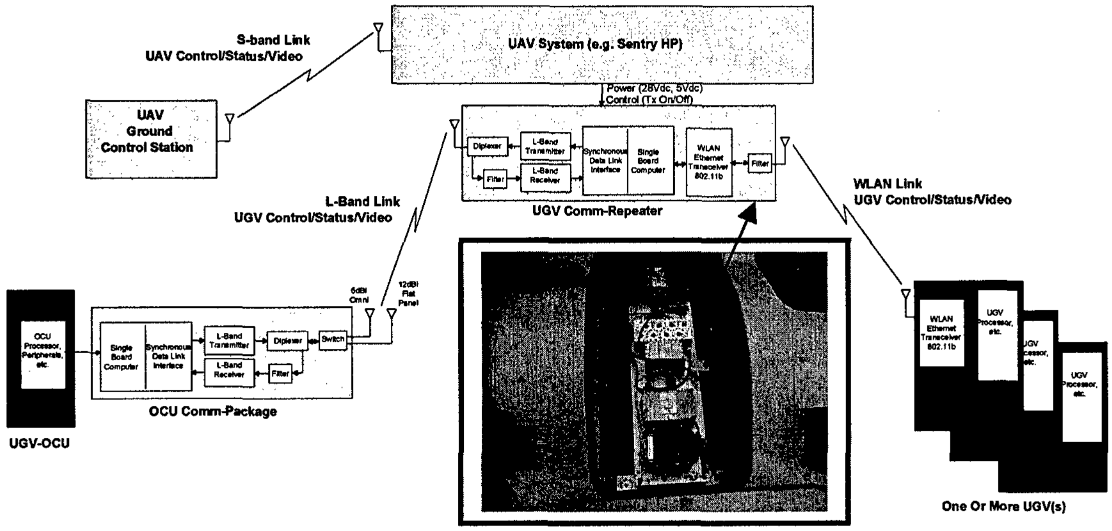

Figure 1-2: UGV Communications Repeater System

The UGV comm-repeater system consists of two assemblies: the OCU comm-package and the UGV comm-repeater payload. Command and control signals generated at the OCU are provided to the OCU comm-package via an ethernet interface. This data is subsequently translated by the OCU comm-package into High Level Data Link (HDLC) format for wireless transmission via L-band, 1.7GHz, transceiver equipment to the UGV comm-repeater payload. At the UGV comm-repeater payload, the HDLC data is received via L-band transceiver equipment and converted back into ethernet packet form. Single board computers perform data translation on each side of the L-band telemetry link. Once received, ethernet command/control data is subsequently broadcast to the UGV(s) via WLAN transceiver equipment operating in the 2.4GHz FCC Part-15 unlicensed frequency band.

While the L-band telemetry link side of the system utilizes point-to-point communication, the WLAN link is implemented by point-to-multipoint network centric communication using commercially available IEEE-802.11 wireless ethernet transceivers. In WLAN terminology, the UGV Comm-Repeater functions as the Access-Point (AP) and each UGV functions as a Station-Adaptor (SA). One AP detects, establishes, and maintains communications with one or more SAs within a listening area. Building upon this architecture, a single OCU can be used to control the operation of one or more UGVs and the range of UGV operation can be extended to BLOS via the L-band telemetry link equipment and transparent data translation processing of the UGV comm-repeater link.

2. METHODOLOGY

2.1. Demonstration Plan

2.1.1. General

Two basic objectives of this initiative were to emplace a UGV into a desired environment and to extend the range of control for that UGV beyond current system capabilities. As a risk mitigation effort, integration tests were performed near the UAV contractor's facility at Mineral Wells, TX before Phase I and II were accomplished. After successful integration test, both Phase I and II were demonstrated concurrently at Eglin AFB, FL. The knowledge gained from this initiative will provide key inputs to the USSOCOM Pathfinder ACTD.

2.1.2. Scope of Demonstration

The Stork initiative has concluded two demonstration phases. Phase I and II were conducted 20 March 2003 through 27 March 2003 at Auxiliary Field Six, Eglin AFB, FL. A tactical UAV produced by DRS Unmanned Technologies was chosen for this demonstration because of its size, range, payload, and other demonstrated capabilities. To reduce integration risks, two Sentry HP UAVs were modified; one to emplace a UGV and the other one to carry a UGV communications relay. (Note: One Sentry HP UAV could be used to both drop a UGV and perform as a communication relay.)

Phase I was designed to select a UGV to drop, develop a harness system to support and release the UGV, and then evaluate the delivery method developed to emplace the UGV. The EEL UGV was selected because its size, weight, and durability characteristics were compatible for air deployment.

Phase II was designed to create and integrate a communications relay into the Sentry HP UAV and then evaluate its effectiveness. Two JAUS capable UGVs, ARTS and Matilda (JAUS was integrated on Matilda for this demonstration), were selected for the evaluation part of this phase. Wintec, under direction from AFRL, designed tested, and integrated the communications relay and performed the JAUS integration.

2.1.3. Method of Demonstration

During Phase I, three airdrops of the EEL were made to evaluate the effectiveness of the delivery system. All UGV flights released the UGV at 400 ft AGL. The UAV slung the EEL UGV externally to its underside. The release point was calculated using a target Global Positioning System (GPS) coordinate, wind speed and wind direction. The UGV, upon release, immediately deployed its parachute, which mechanically detached as the EEL landed. Then, the EEL operator evaluated the EEL for its condition and proper operation. Time limitations prevented JAUS from being integrated onto the EEL, and, therefore, it wasn't controlled via the communications relay.

During Phase II, the effectiveness of the UGV communication link was evaluated. Two JAUS capable UGVs, ARTS and Matilda, were controlled via the communications relay on the Sentry HP. The OCU controlled each UGV, switching back and forth as the "mission" dictated. The "mission" consisted of a simple course created for the UGVs to traverse in order to evaluate the effectiveness of the communications relay. The distance between the OCU and the UAV was incrementally increased to determine the maximum distance the OCU could be stationed away from the UGVs and still retain effective control of the UGVs. The UAV operated in a stable orbit centered on the UGV area of operations and its altitude was varied from 1000 ft to 2500 ft.

The primary goal of the Stork initiative was to prove UAV/UGV integration could both deliver UGV sensors into an area of concern and extend the range of control for UGVs. The following objectives were created to meet this goal:

Objective #1: Demonstrate communications solution to remotely control a UGV and its sensor beyond current system ranges.

Objective #2: Demonstrate the delivery of a UGV by a UAV into a desired area.

Objective #3: Demonstrate effectiveness of JAUS to control two UGVs through a communications relay.

Objective #4: Demonstrate effectiveness of UAV/UGV integration to provide persistent target information.

2.1.4. Method of Measurement

In the functional flight demonstration portion of Phase I, the EEL UGV operators collected the pertinent data to assess the Stork UGV delivery system for each of the three drops. An assessment of the EEL's communication link, mobility, video quality, and delivery system was made after each drop. For Phase II, the ARTS and Matilda UGV operators collected data to access the operation of the UGVs and recorded it using an OCU Test Information Sheet. Log data files from the UAV GCS, communications relay, and OCU were used to generate a Quicklook Report after each flight. The L-Band and WLAN communications links effectiveness were evaluated at various attitudes and positions. Of particular interest was possible L-band link loss due to vehicle wing or strut shading of antennas. Table 2-1 illustrates the specific measures that were used to evaluate each objective.

Table 2-1: Measurements by Objective

Objective	Measurements
Demonstrate communications solution to remotely control a UGV and its sensors beyond current system ranges (1-2 km).	A qualitative measurement indicating the ground track distance, in kilometers, that a UGV and its sensors were controlled from an OCU.
Demonstrate the delivery of a UGV by a UAV into a desired area.	A binary (yes/no) measurement indicating whether the UGV was delivered into the desired area.
Demonstrate effectiveness of JAUS to control two UGVs through a communications relay	A binary (yes/no) measurement indicating whether two UGVs were controlled through the communications relay.
Demonstrate effectiveness of UAV/UGV integration to provide persistent target information for IPB	A binary (yes/no) measurement indicating whether the UGV provides target information to the operator.
	A qualitative measurement indicating the percentage of uptime of the L-Band link.
	A qualitative measurement indicating the percentage of uptime of the WLAN link.

2.2. Integration

2.2.1. Phase I EEL UGV Integration

The first UAV was integrated to carry and deploy the EEL UGV. The Stork design constraints included: vehicle survivability after a 15 ft/sec impact, a size envelope not larger than 1'x1.5'x2.5', and a weight limit of 65 pounds. Initial shock tests at CSS showed that pneumatic tires could successfully mitigate the initial impact g forces seen by the EEL's internal electronics. Additional requirements included a bi-directional radio link for command and control and a uni-directional video link to the OCU. Electrical power was provided by two 12 volt, 7.2 ampere-hour lead acid gel cell batteries connected in parallel.

Nominal vehicle speed was 1 meter/second with a run time of two hours. An AMD 188ES based 16-bit micro-controller, flux gate compass, and GPS receivers supported vehicle geo-location and operation either in joystick or waypoint navigation modes. The command, control, and communication channel was comprised of two industrial, scientific, and medical band spread spectrum modems (902-928 MHz). For remote tele-operation of the UGV, a wide-angle analog color camera and a L-band video link provided visual feedback. Vehicle nominal weight was 54 lbs. Early tests confirmed a payload capability of 17 additional pounds while maintaining adequate mobility on hard surfaces, sand, and gravel.

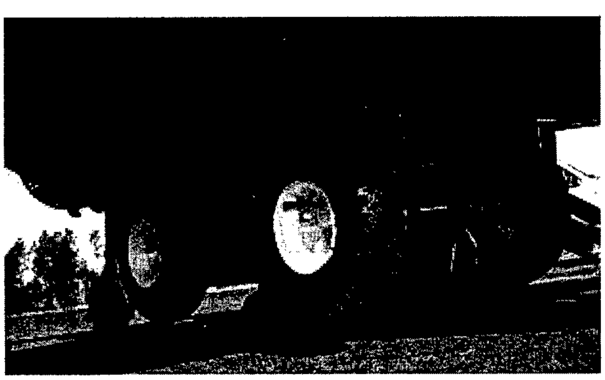

Figure 2-1: EEL Support Brace

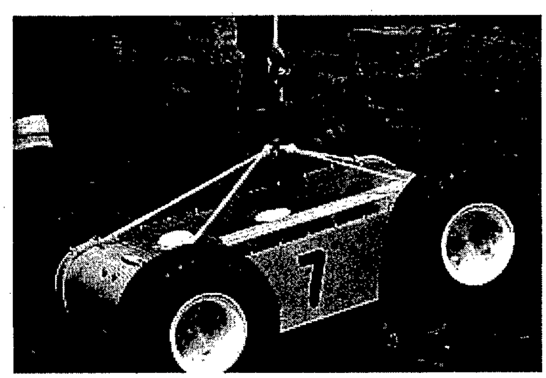

Figure 2-2: Weight-off Release

A support brace for the UGV was mounted to the underside of the UAV and can be seen in Figure 2-1. A parachute was selected that would allow a 15 ft/s descent rate for the EEL and was connected via a harness to the EEL. The harness system was designed to land the EEL horizontally for a four-point landing. A system of straps secured the EEL to the UAV and an electro/mechanical cutter was selected as the EEL release mechanism from the UAV. A hydraulic "weight off" release attached to the EEL's harness (Figure 2-2) was used to release the parachute on impact.

As a risk mitigation measure, DRS Unmanned Technologies performed three "dummy" drops with a simulated EEL payload at their Texas facility to ensure the proper deployment capability of this system. This delivery system, which included a two-point harness, was then tested with an operational EEL vehicle. The EEL landed on one wheel instead of two; the increased stress caused a gear failure on a drive mechanism. Therefore, a four-point harness was designed to keep the EEL horizontal on descent to allow for a four-point landing.

2.2.2. Phase II UGV Communication Relay Integration

The second UAV was integrated to carry the UGV communications relay internally. To allow other users to employ this relay, it was also designed for a dual installation capability on an external pod as depicted in Figure 2-3. Prior to the Eglin demonstration, integration testing was performed on the UGV communication relay at Mineral Wells, TX, at the contractor's facility. Integration tests were used to verify successful integration of the UGV communication relay into the Sentry HP. Initial characterization of the WLAN and L-band links as a function of the position of the Sentry HP were performed (only the Matilda UGV was brought to the DRS facility for integration testing). Figure 2-4 illustrates the OCU configuration used for the integration test. Interference issues between UAV control links and UGV communication relay equipment were also checked and no problems were noted.

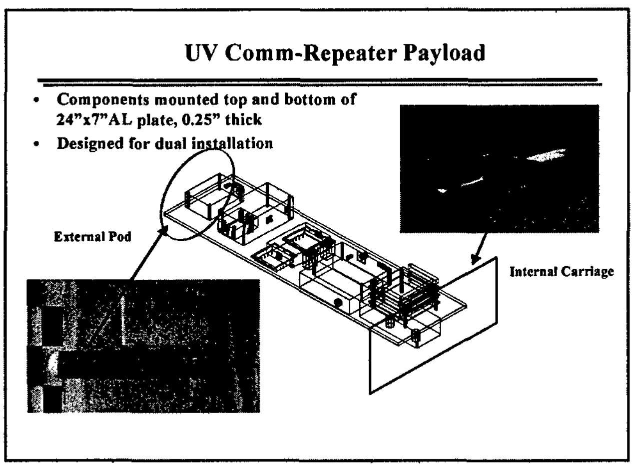

Figure 2-3: UGV Comm-Relay

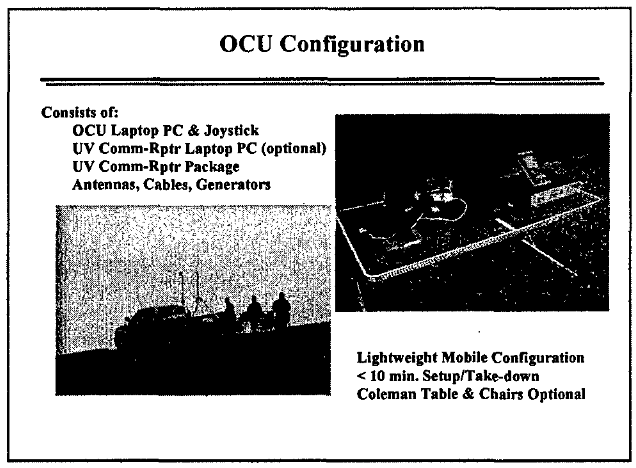

Figure 2-4: OCU Configuration

From the integration tests, it was determined that the UGVs had to operate under certain conditions. The biggest limitation was total bandwidth utilization including both L-band and WLAN links. From previous testing, L-band maximum throughput was set at 1.7 Mbps.

2.3. Demonstration Team, Location, and Dates

2.3.1. Team

A number of organizations were involved in the Stork demonstration. The UAVB and AFRL were responsible for oversight and management of the demonstration. AFRL was also responsible for JAUS integration onto the Matilda. USSOCOM provided warfighter support and the Matilda UGV for this effort. AFSOC and USSOCOM partnered in CONOPs exploitation. DRS Unmanned Technologies provided the UAV support. Wintec developed the communications relay, performed integration and demonstration tests, and assessed the results. Coastal System Station provided the EEL and performed impact tests to conclude it was safe to drop from a UAV.

2.3.2. Location and Dates

Initial bench level test were performed at Wintec, Fort Walton Beach, FL, in early November 2002. The UGV communication relay ground tests were conducted at Tyndall AFB, from 21 November through 6 December 2002. The EEL was conceived, designed, and tested by the Coastal Systems Station's Surf Zone Robotics team from June 2002 through March 2003. Integration tests were conducted at Mineral Wells, TX, from 24 February 2003 through 01 March 2003. The functional flight demonstration was conducted at Eglin AFB, from 19 March 2003 through 26 March 2003. A distinguished visitors demonstration day was conducted on 27 Mar 2003.

3. DATA

Data from the ground and flight tests are shown below. Table 3-1 shows a summary of objectives achieved during each of the tests. Table 3-2 shows the percentage of uptime, downtime and degraded time of the communications links. The WLAN is the link between the communications relay and the UGVs. The L-band link is between the OCU and the communications link. Figure 3-1 shows the L-band signal loss points as a function of position.

Table 3-1: Primary Objective Results by Flight Test

Test Number	Distance OCU to UGVs	Objective 1	Objective 2	Objective 3	Objective 4
Ground Test 1	0.3 NM	Degraded	N/A	Degraded	
Flight Test 1	0.7 NM	Degraded	N/A	Degraded	
UGV Drop Test 1		N/A	Pass	N/A	N/A
Flight Test 2	0.7 NM	Degraded	N/A	Degraded	
UGV Drop Test 2		N/A	Pass	N/A	N/A
Flight Test 3	13.9 NM	Degraded	N/A	Degraded	
Flight Test 4	5.0 NM	Degraded	N/A		
Flight Test 5	5.0 NM	Pass	N/A	Pass	Pass
Flight Test 6	5.0 NM	Pass	N/A	Pass	Pass
Flight Test 7	13.9 NM	Degraded	N/A	Degraded	Degraded
Flight Test 8	19.2 NM		N/A		
Flight Test 9	17.0 NM		N/A		
Flight Test 10	13.9 NM	Pass	N/A	Pass	Pass
DV Demo	13.9 NM	Pass	Pass	Pass	Pass

Table 3-2: Link Performance Results

Test Number	Distance OCU to UGVs	L-band Link %Up	L-band Link Degraded	L-band Link %Dwn	WLAN Link %Up	WLAN Link Degraded	WLAN Link %Dwn
Ground Test 1	0.3 NM E						
Flight Test 1	0.7 NM E						
UGV Drop Test 1		N/A	N/A	N/A	N/A	N/A	N/A
Flight Test 2	0.7 NM E						
UGV Drop Test 2		N/A	N/A	N/A	N/A	N/A	N/A
Flight Test 3	13.9 NM SE						
Flight Test 4	5.0 NM SE						
Flight Test 5	5.0 NM SE	97.6%	1.6%	0.8%	92.8%	N/A	7.2%
Flight Test 6	5.0 NM SE	97.3%	2.0%	0.7%	95.0%	N/A	5.0%
Flight Test 7	13.9 NM SE	74.7%	7.0%	18.3%	66.0%	N/A	34.0%
Flight Test 8	19.2 NM E		0.0%	100.0%		N/A	100.0%
Flight Test 9	17.0 NM E		0.0%	100.0%		N/A	100.0%
Flight Test 10	13.9 NM SE	94.8%	4.1%	1.1%	93.5%	N/A	6.5%
DV Demo	13.9 NM SE	97.6%	1.8%	0.6%	92.1%	N/A	7.9%

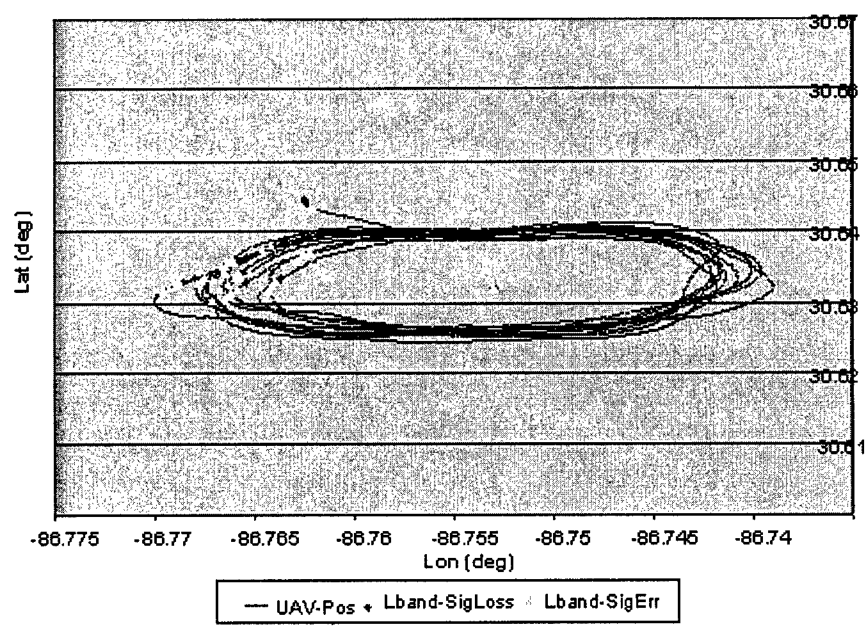

Figure 3-1: L-Band Loss vs. UAV Lat/Long

4. RESULTS

This section describes the results of trying to achieve each objective

4.1. Objective #1 Result

Objective #1 was to demonstrate communications solution to remotely control a UGV and its sensors beyond current system ranges (1-2 km). Result: The UGVs in this demonstration were controlled by an OCU 26 kilometers away.

4.2. Objective #2 Result

Objective #2 was to demonstrate the delivery of a UGV by a UAV into a desired area. Result: The UAV successfully delivered the UGV.

4.3. Objective #3 Result

Objective #3 was to demonstrate effectiveness of JAUS to control two UGVs through a communications relay. Result: Both the ARTS and Matilda UGVs were successfully controlled a single OCU via the communications relay.

4.4. Objective #4 Result

Objective #4 was to demonstrate effectiveness of UAV/UGV integration to provide persistent target information. The UGV successfully provided target information to the operator. The uptime of the L-Band link (OCU to UAV communications relay) at a range of 26 km was 94.8% of the time. The uptime of the WLAN link (UAV communications relay to UGV) at a range of 26 km was 93.5% of the time.

5. ANALYSIS AND CONCLUSIONS

5.1. General

The Stork initiative successfully demonstrated all four objectives of this project. The conclusions made based on the observed results from this demonstration for each objective are discussed below.

5.2. Conclusions on Objective #1

The Stork system was able to increase the range of control of a UGV from 2 km to 26 km on the L-band link side of the communications relay. The maximum distance noted for the WLAN side of the communication link was 7443 feet. Due to the extended ranges, it was necessary to boost WLAN performance using 1-watt bi-directional amplifiers, which inevitably degraded system throughput. The gauge used for measuring useable throughput was the integrity of the link, which translated from the percentage of dropped RF packets and number of retries. More retries resulted in longer successful transmission times, and consequently greater data latency. This seriously compromised the ability to tele-remotely operate the UGVs in real-time. To avoid this, the maximum number of retries was decreased to two. This ensured lower latency times, but increased the percentage of dropped packets. Acceptable UGV operational threshold values were determined to be a maximum 20% packet loss and a maximum bandwidth utilization of 1.0 Mbps. Effective throughput of the communications relay was less than 1.0 Mbps as seen in Table 5-1.

Table 5-1: Comm-Link Effective Throughput

	Data Rate	Effective Throughput	Comments
L-band Components:			
L-band Tx/Rx Gear	10 Mbps	5 Mbps	Reduced by 1/2 due to Manchester coding
Synchronous Data Link	2 Mbps	1.7 Mpbs	Results of lab testing at WINTEC
WLAN Components:			
Cisco WLAN Gear	11 Mbps	7 Mbps	
BreezeComm Gear	3 Mbps	2 Mbps	Replaced with Cisco gear prior to DRS/TX and Eglin test activities
WLAN Amplifiers		< 1.0 Mbps	Anomalie observed during extensive testing of WLAN amplifiers from two different manufacturers
Comm-Rptr System		**< 1.0Mbps**	Stable performance between 0.5 and 1.0 Mbps

5.3. Conclusions on Objective #2

The Sentry HP successfully deployed a UGV into a desired area. The EEL separated cleanly from the UAV, deployed successfully into the landing zone, detached from its parachute, and was fully operational after it landed for all three EEL drops. The first EEL drop, however, released the EEL early at an altitude of about 30 feet AGL. The EEL was unaffected by the early release which clearly illustrates its ruggedness. A rope extension was added to the EEL's harness that relieved torque on the release mechanism and no more problems were noted. All the UGV drops were within 500 feet of the target drop location.

5.4. Conclusions on Objective #3

Both the ARTS and Matilda UGVs were controlled through the communications relay at a distance of 26 km. During the data runs, multiple vehicle operation was accomplished using a single OCU and switching between the ARTS and Matilda. This mitigated unnecessary bandwidth use as data (except for position, velocity, and status) from the idle vehicle was stopped. This played favorably into keeping within the bandwidth requirements for adequate control of the UGVs. Also, control latency values were observed to be within acceptable limits (0.1-0.3 seconds). To stay within the bandwidth threshold of 1.0 Mbps, the video settings were individually set for both ARTS and Matilda. The ARTS had a higher resolution camera (compared to the Matilda), thus resulting in larger output video data. To account for the disparity in data size, the video rate was different for each UGV, thus also preserving the same image quality as viewed on the OCU (See Table 5-2).

Table 5-2: Video Configuration

UGV	ARTS	Matilda
Data Rate (Hz)	5	8
Resolution	352 x 240	352 x 240
%Compression	50	50
Bandwidth Use (Mbps)	0.4 – 0.6	0.3 – 0.5

5.5. Conclusions on Objective #4

Target information was provided to the operator through the communications relay. For the demonstration, the Matilda UGV was used to gather the target information. The Matilda was able to approach a target vehicle residing in a open ended structure and send back video at a rate of 8 hertz and a resolution of 352 x 240 to its operator. The Matilda was also able to operate and send back video from inside the shelter. The orbit of the UAV was established such that line of sight from the UAV to the Matilda would not be lost as the Matilda entered the structure. The uptime of the L-band link at 26 km was over 94 percent. The uptime of the WLAN link at 26 km was over 93 percent (Table 3-2).

5.6. Observations and Comments

During the first ground test and flight test 1 through 4, the effectiveness of the OCU to control the UGVs was degraded or unacceptable. Several problems were discovered and corrected. The first problem was that the antenna routing in the OCU van used several connectors to route the cable to the top of the antenna mast. Each one of these connectors incorporated a signal loss that degraded the system. To eliminate this problem the cable was routed outside the OCU van to avoid these connectors. The second problem was an omni-directional antenna was necessary for the tests at less than 1 nm. The omni-directional antenna had a gain of only 7 dBs while the flat panel directional antenna had a gain of 12 dBs. The third problem was that the bandwidth requirement of the ARTS and Matilda combined exceeded the maximum bandwidth available (1 Mbps) for acceptable UGV operations. The ARTS video rate was reduced from 15 Hz to 5 Hz to reduce the bandwidth requirement. After these changes were made, flight tests 5 and 6 were successful. For flight test 7, a new 75' cable was installed on the OCU so that the mast could be fully extended. This length of cable produced a signal loss of 10.1 dBs, which was excessive for the system to operate effectively. Therefore, the original 25' (3.4 dBs) cable was reinstalled. Then, the final two flight tests at 26 km were successful

When the L-band link loss was plotted against the latitude/longitude, a trend was seen as shown in Figure 3-1. It is evident from this graph that the position of the UAV does make a difference to the L-band signal loss.

ACKNOWLEDGMENTS

The authors would like to recognize the following organizations for their members' participation in and/or support of this demonstration:

Applied Research Associates
6th Ranger Training Battalion
720th Special Tactics Group
Air Force Research Laboratory, Tyndall AFB
AFSOC
DRS Unmanned Technologies, Inc.
Defense Threat Reduction Agency
Naval Surface Warfare Center – Panama City
Office of Naval Research
Titan Corp.
USSOCOM
UAV Battlelab
Wintec

REFERENCES

1. D. Clapp, *UAV/UGV Communication Repeater System Final Report,* Wintec, Inc., Ft. Walton Beach FL, May, 2003.

2. J. Price, *Stork Initiative Final Report,* USAF Unmanned Aerial Vehicle Battlelab, Tyndall AFB, FL, May, 2003.